CHAPTER 30

GROUPING OF CELLS

The t.p.d. of a cell is dependent on the materials used as the cathode and anode. The magnitude of this t.p.d. is limited, in the case of a dry cell to 1.5 V while a secondary cell will produce a t.p.d. of 2 V. As power is equal to EI, operating at low voltages restricts the quantity of power a cell can deliver. Current delivered by a cell is largely dependent on electrode area. In the case of primary cells this area is limited, due to small physical-size of the portable cells, thus again restricting power output. To provide an increased t.p.d., cells are connected in series while the current drawn from a group of cells can be increased by connecting cells in parallel. Both increased t.p.d. and current can be produced from cells by connecting the cells in series parallel.

30.1 CELLS IN SERIES

Cells are connected in series to increase the open circuit t.p.d. available from the group. In practical applications the individual cells are placed in a common case and permanently joined together to form a battery. Most non commercial vehicles use 12 volts for their electrical system, this 12 volts being obtained from six-2 volt batteries connected in series.
cells

Like all series circuits, the series group of cells has one common current. (Figure 30.1).

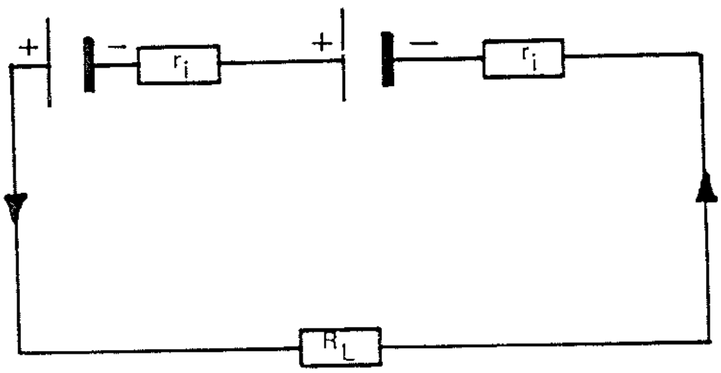

Figure 30.1

Only identical type cells are normally used in cell grouping. The total circuit resistance in the series group of cells shown in Figure 30.1 is -

$$R = r_i + r_i + R_L$$

Being identical cells, it may be assumed that the characteristics of each cell are the same, that is, the internal resistance and open circuit t.p.d. of each cell has the same value, so —

$$R = 2\,r_i + R_L$$
$$= n_s\,r_i + R_L$$

Where r_i is the internal resistance of each cell and n_s equals the number of cells in series.

From Kirchhoff's voltage law around the circuit —

$$E_1 - Ir_1 + E_2 - Ir_2 - IR_L = 0$$

or $$E_1 + E_2 = Ir_1 + Ir_2 + IR_L$$

From the previous paragraph $E_1 = E_2$ and $r_1 = r_2$ so the total e.m.f. of the group -

$$n_sE = I\,(n_s\,r_i + R_L)$$

and for the current in the circuit —

$$I = \frac{n_sE}{n_sr_i + R_L} \text{ amperes}$$

Example 30.1

Six cells, each with an open circuit t.p.d. of 1.5 volts and an internal resistance of 0.1 ohms are connected in series to a load resistance of 2.4 ohms. Calculate —

(a) the current in the circuit.

(b) the internal voltage drop of the group.

(c) the voltage across the load

$E = 1.5 \text{ V}$

$r_i = 0.1 \text{ ohms}$

$R_L = 2.4 \text{ ohms}$

$I = ? \text{ A}$

$V_i = ? \text{ V}$

$V_2 = ? \text{ V}$

$$I = \frac{n_s E}{n_s r_i + R_L} = \frac{6 \times 1.5}{(6 \times 0.1) + 2.4} = \frac{9}{3} = 3 \text{ A}$$

$$V_i = I \times n\, r_i = 3 \times 6 \times 0.1 = 1.8 \text{ V}$$

$$V_L = I R_L = 3 \times 2.4 = 7.2 \text{ V}$$

Example 30.2

When three cells, each with an open circuit voltage of 1.5 volts are connected in series to a 2.4 Ω resistor a current of 1.5 amperes passes through the resistor. Calculate the internal resistance of each cell.

$E = 1.5 \text{ V}$

$I = 1.5 \text{ A}$

$R_L = 2.4\ \Omega$

$r_i = ?\ \Omega$

$$R = \frac{n_s E}{I} = \frac{3 \times 1.5}{1.5} = 3\ \Omega$$

$$R = n_s r_i + R_L$$

$$n_s r_i = R - R_L = 3 - 2.4 = 0.6\ \Omega$$

$$r_i = \frac{0.6}{n_s}$$

$$r_i = \frac{0.6}{3} = 0.2\ \Omega$$

30.2 PARALLEL GROUPING OF CELLS

In principle, cells are grouped in parallel to increase the current that may be drawn from the group. The result of connecting cells in parallel is to increase the overall effective plate area of the cell group. A parallel cell circuit is shown in Figure 30.2.

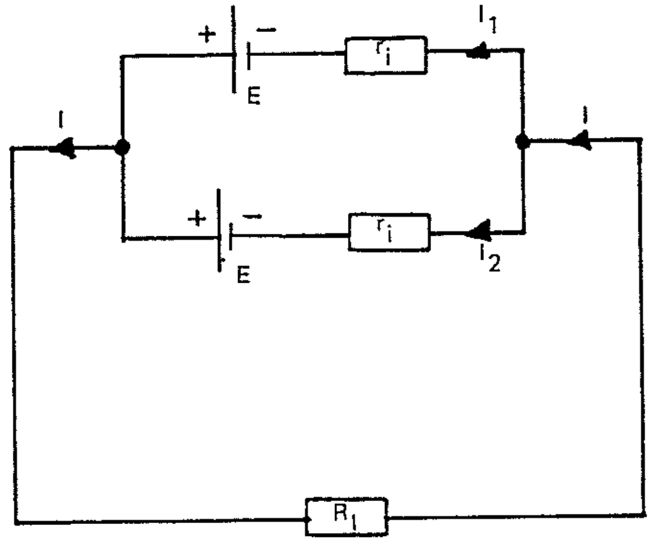

Figure 30.2

The total resistance of the internal resistances of the cell group will be —

$$\frac{r_i}{2} \quad \text{or} \quad \frac{r_i}{n_p}$$

Where, n_p is the number of parallel branches. The total resistance of the parallel group circuit will be —

$$R = \frac{r_i}{n_p} + R_L$$

The sources being connected in parallel will produce an e.m.f. which is equal to the e.m.f. of one cell.

$$E = E_1 = E_2$$

The total current in the circuit is equal to the e.m.f. of one cell divided by the total resistance of the circuit.

$$I = \frac{E}{\frac{r_i}{n_p} + R_L}$$

Example 30.3

Six cells, each having a t.p.d. of 1.5 volts and an internal resistance of 0.3 ohms, are connected in parallel. The group is then connected to a load resistor of 2.45 ohms.

Calculate —

(a) the current in the load resistor

(b) the voltage drop . *in the cells*

(c) the voltage across the load

$E = 1.5\ V$

$r_i = 0.3\ ohms$

$R_L = 2.45\ ohms$

$I = ?\ A$

$V_i = ?\ V$

$$I = \frac{E}{\frac{r_i}{n_s} + R_L}$$

$$= \frac{1.5}{\frac{0.3}{6} + 2.45}$$

$$= \frac{1.5}{0.05 + 2.45}$$

$$= 0.6\ A$$

$$V_i = \frac{I\ r_i}{n_s}$$

$$= 0.6 \times 0.05$$

$$= 0.030\ V$$

$$V_L = I\ R_L$$

$$= 0.6 \times 2.45$$

$$= 1.470\ V$$

Example 30.4

Three cells, each with an open circuit t.p.d. of 1.5 volts are connected in parallel to a 4.9 Ω resistor. If a current of 0.3 A passes through the resistor. calculate the internal resistance of each cell.

$E = 1.5\ V$

$I = 0.3\ A$

$R_L = 4.9\ \Omega$

$r_i = ?\ \Omega$

$$R = \frac{E}{I}$$

$$= \frac{1.5}{0.3}$$

$$= 5\ \Omega$$

$$R = \frac{r_i}{n_p} + R_L$$

$$\frac{r_i}{n_p} = R - R_L$$

$$= 5 - 4.9$$

$$= 0.1\ \Omega$$

$$r_i = n_p \times 0.1$$

$$= 3 \times 0.1$$

$$= 0.3\ \Omega$$

30.3 SERIES PARALLEL GROUPING OF CELLS

Cells are series paralleled when both a higher t.p.d. and current are required from the group. The method used in solving series parallel resistor circuits may be applied to find the total internal resistance of the cell group. (Figure 30.3).

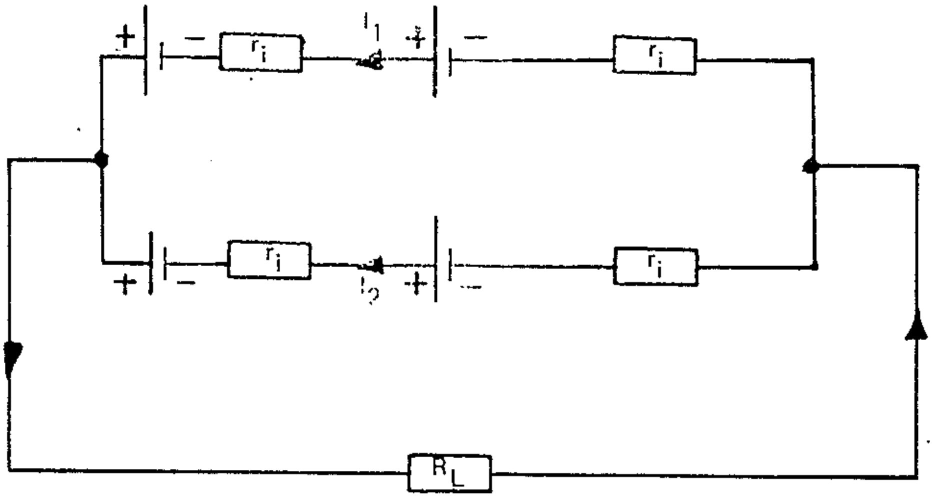

Figure 30.3

First find the total resistance and t.p.d. of each series branch. The t.p.d. of each series group is the t.p.d. that is applied to the circuit, while the resistance of a series branch divided by the number of parallel branches will give the total internal resistance.

Let r_i = internal resistance of each cell.

Then $n_s\ r_i$ = internal resistance of each series branch.

and $\frac{n_s\ r_i}{n_p}$ = total internal resistance of the group.

The resistance of the complete circuit will be -

$$R = R_L + \frac{n_s\ r_i}{n_p}$$

The t.p.d. of the group will be

$$E = n_s\ E$$

and the current in the external circuit is calculated by the equation

$$I = \frac{n_s E}{R_L + \frac{n_s\ r_i}{n_p}}$$

Example 30.5

Six cells, each having a t.p.d. of 1.5 volts and an internal resistance of 0.1 ohms are connected in two parallel branches, each branch consisting of three cells. If an external resistance of 2.35 ohms is connected to the group, calculate —

(a) the current in the external circuit

(b) the voltage drop across the load resistor

$E = 1.5 \text{ V}$

$r_i = 0.1 \text{ ohm}$

$R_L = 2.35 \text{ ohms}$

$I = ? \text{ A}$

$V_L = ? \text{ V}$

$$I = \frac{n_s E}{\frac{n_s r_i}{n_p} + R_L}$$

$$= \frac{3 \times 1.5}{\frac{3 \times 0.1}{2} + 2.35}$$

$$= \frac{4.5}{0.15 + 2.35}$$

$$= \frac{4.5}{2.5}$$

$$= 1.8 \text{ A}$$

$$V_L = I R_L$$

$$= 1.8 \times 2.35$$

$$= 4.23 \text{ V}$$

Example 30.6

Twelve cells, each with an open circuit voltage of 1.5 V are connected to produce an overall t.p.d of 6 volts. If the cell grouping delivers 3 A when connected to a resistor of 1.8 , calculate the internal resistance of each cell.

$E = 1.5 \text{ V}$

$I = 3 \text{A}$

$R_L = 1.8\ \Omega$

$r_i = ?\ \Omega$

$$n_s = \frac{6}{1.5}$$

$$= 4$$

$$n_p = \frac{12}{4}$$

$$= 3$$

$$R = \frac{n_s E}{I}$$

$$= \frac{4 \times 1.5}{3}$$

$$= 2\ \Omega$$

$$R = \text{total } r_i + R_L$$

$$\text{total } r_i = R - R_L$$

$$= 2 - 1.8$$

$$= 0.2\ \Omega$$

$$\text{total } r_i = \frac{n_s r_i}{n_p}$$

$$0.2 = \frac{4 \times r_i}{3}$$

$$r_i = 0.15\ \Omega$$

Equations in this chapter

(1) $$I = \frac{n_s E}{n_s r_i + R_L} \quad \text{(series cells)}$$

(2) $$I = \frac{E}{\frac{r_i}{n_p} + R_L} \quad \text{(parallel cells)}$$

(3) $$I = \frac{n_s E}{R_L + \frac{n_s r_i}{n_p}} \quad \text{(series parallel cells)}$$

TUTORIALS 1.30

(1) Six 1.5 volt dry cells are connected in series to a circuit whose resistance is 4.4 Ω . If the internal resistance of each cell is 0.1 Ω , calculate the current delivered by the cell group.

(2) Twelve 1.5 volt cells are connected in parallel to a load of 3.2 Ω . If the current drawn from the cell group is 0.3 A, calculate the internal resistance of each cell.

(3) Four 1.5 volts cells are connected in series parallel to supply 3 volts to a 2.8 Ω load. If the internal resistance of each cell is 0.2 Ω , calculate the current delivered by each cell.

(4) When twelve 1.5 volt cells, each having an internal resistance of 0.6 Ω , are connected in series parallel to supply 6 V to a resistive load a current of 3 A passes through the load. Calculate the resistance of the load.

(5) Ten . 1.5 volt cells are connected in series parallel to produce an e.m.f. of 7.5 V. If the internal resistance of the cells are 0.2 Ω and the group is connected to a resistor of 0.75 Ω calculate the current delivered by the cell group.